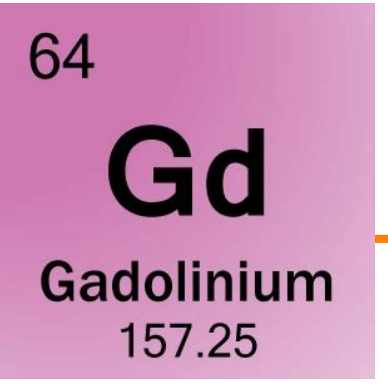

and Water

Pablo F. (IFIC-CSIC, UAM)

DUNE Module of Opportunity Workshop

Brookhaven National Lab. – *2019/11/12*

Outline

- Introduction to Gd-doped water-Cherenkov detectors
- Status of the technology and future steps

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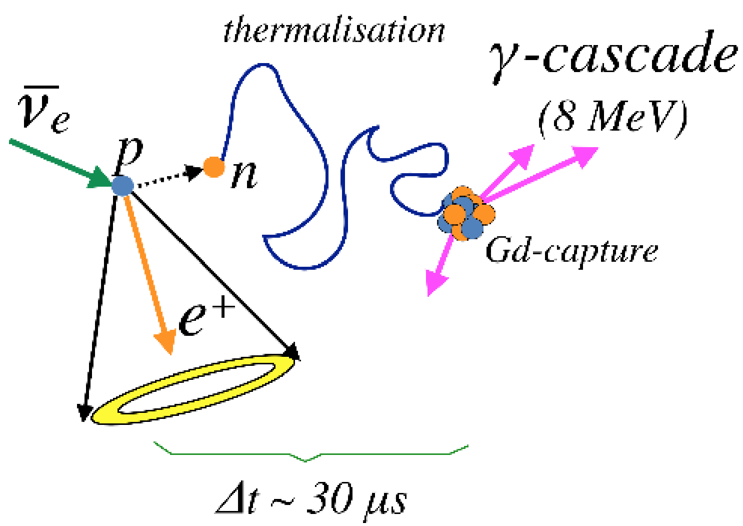

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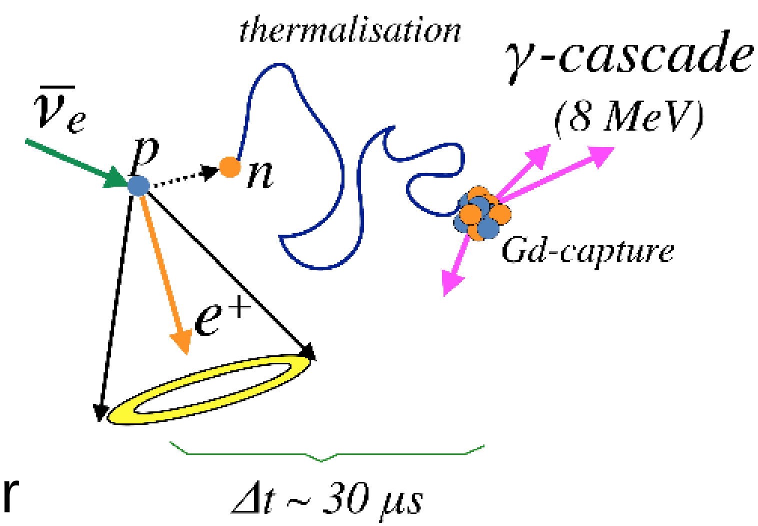

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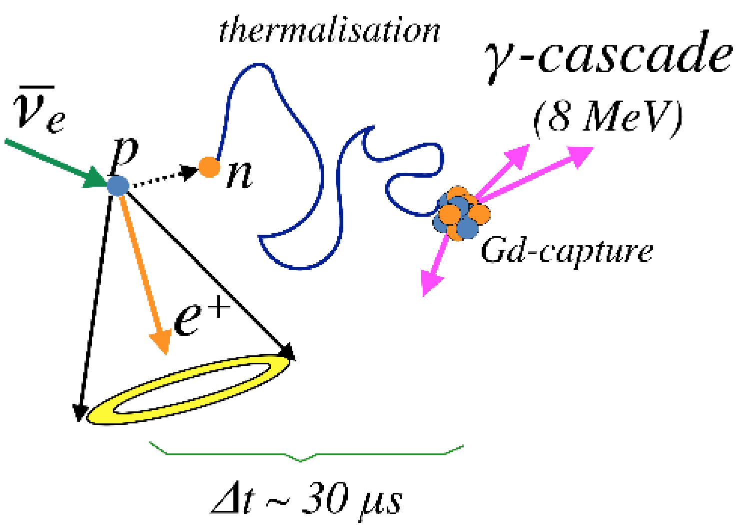

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The neutron propagates for about 2 m in water until it becomes thermal

→ **This time and spatial coincidences are key to relate the Gd-neutron capture signal with the interaction which originated the neutron**

Gd-doped water-Cherenkov detectors

The produced γ-cascade has a mean multiplicity of 4 photons, with a total energy of **~8 MeV** in average, which can be easily measured

Isotope	Natural Abundance (%)	Cross-section (barn)	De-excitation energy (MeV)
152Gd	0.20	1050	6.25
154Gd	2.18	85.0	6.44
155Gd	**14.80**	**60700**	**8.54**
156Gd	20.47	1.71	6.36
157Gd	**15.65**	**254000**	**7.94**
158Gd	24.84	2.01	5.94
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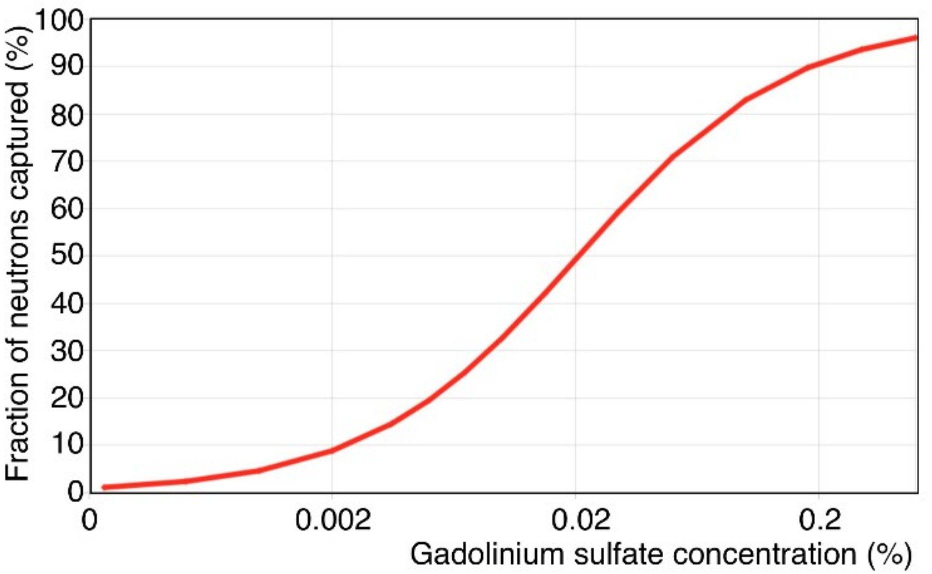
Gd-doping provides, in addition to the charged particles detection, a highly efficient way of detecting neutrons by dissolving a salt of this rare earth into a water-Cherenkov detector



Status and plans of the technology

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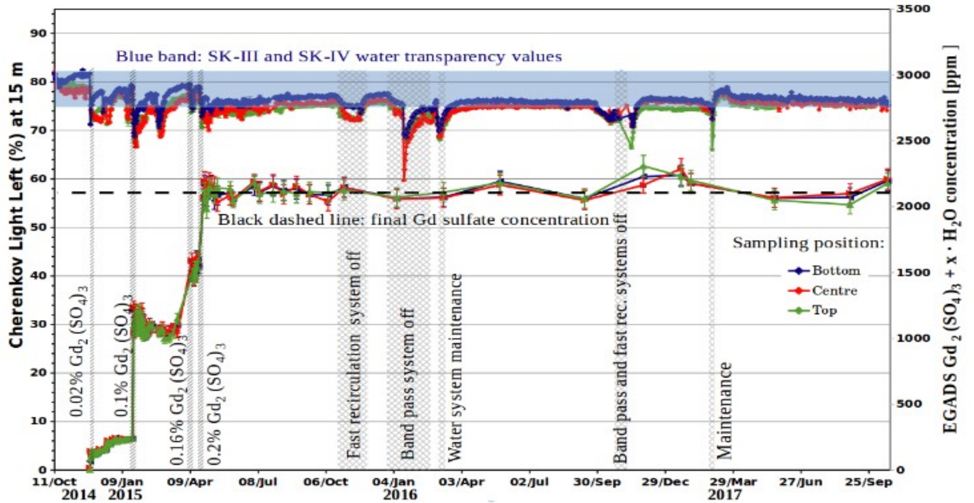

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- Water purification systems
- Water transparency
- Uniformity of Gd
- Impact on detector materials
- Electronics and DAQ
- Gd-induced backgrounds (from impurities)
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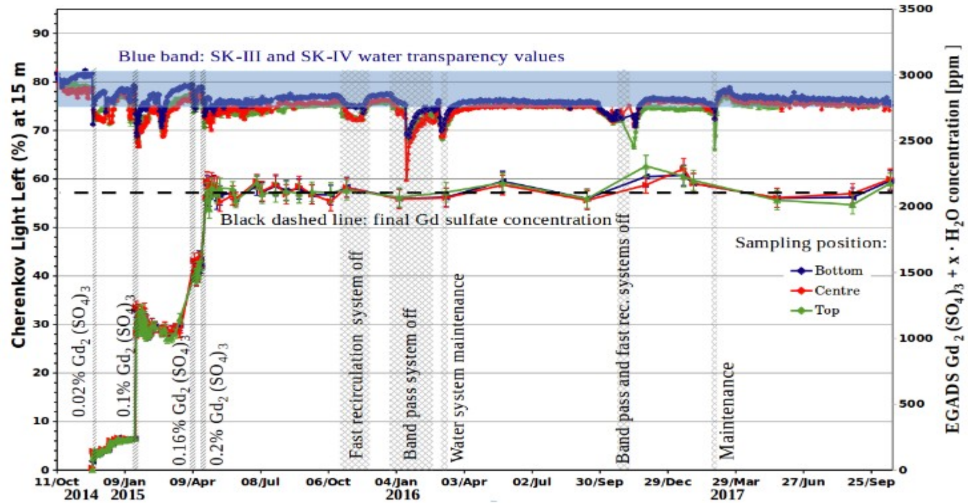

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Therefore, Gd-doped water-Cherenkov detectors are a proven and ready technology

They are also very useful from the physics point of view as this kind of detectors is growing: EGADS, **ANNIE**, **SuperK-Gd**, WATCHMAN, XENONnT water shield, **WCTEC**, IWCD, HyperK (?)

Low energy neutrino physics potential

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A Gd-water-Cherenkov module in DUNE will highly enrich the physics program at low energies with measurements otherwise very challenging for LAr TPCs:

- Standard and NSI solar neutrino physics
- Complementary measurements of supernova bursts with the other modules
- Measurement of the Diffuse Supernova Neutrino Background (DSNB)
- Early supernova warning by measuring the pre-supernova stage

Higher energy physics potential

But Gd-loading also offers benefits at higher energies for proton decay and neutrino physics

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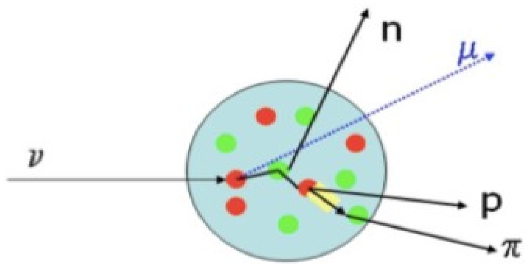
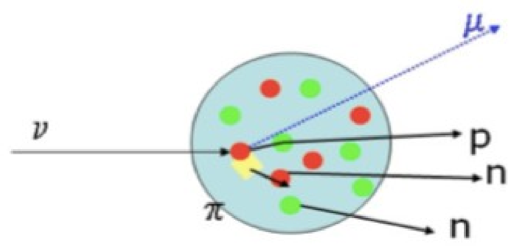
The main background for proton decay searches are atmospheric neutrinos, which usually (>70%) produce at least one neutron

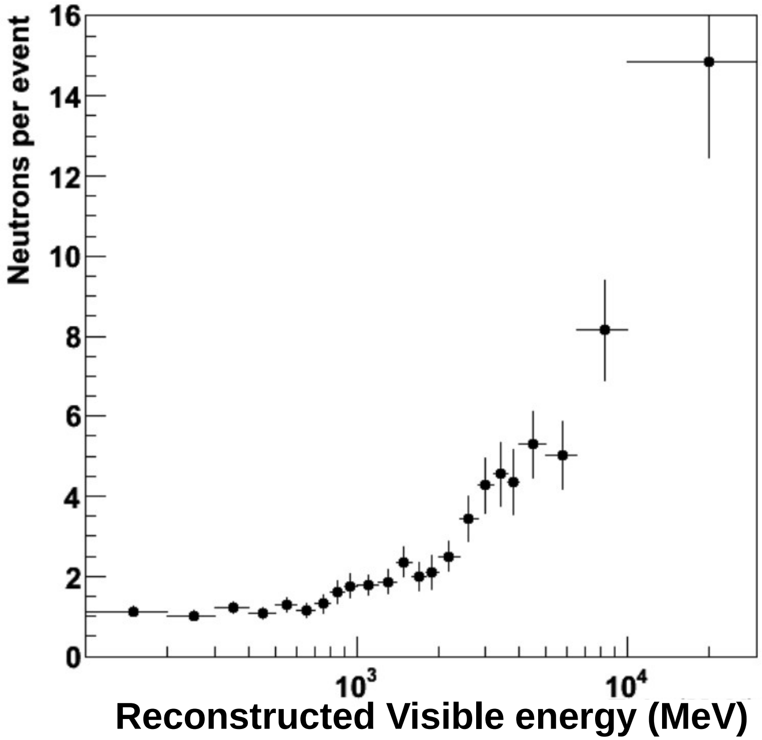
Higher energy physics potential

Neutrino physics:

High energy (>100 MeV) neutrinos interact in various ways and able to produce neutrons from the primary interaction and secondary interactions within the nucleus







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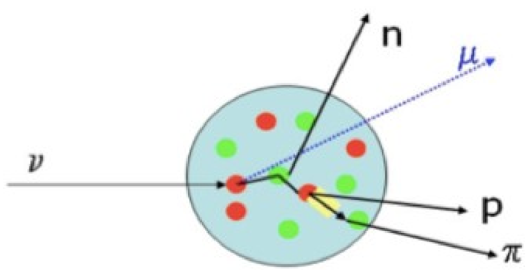

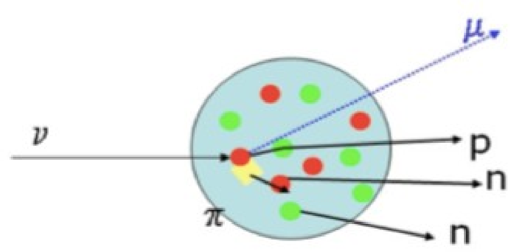

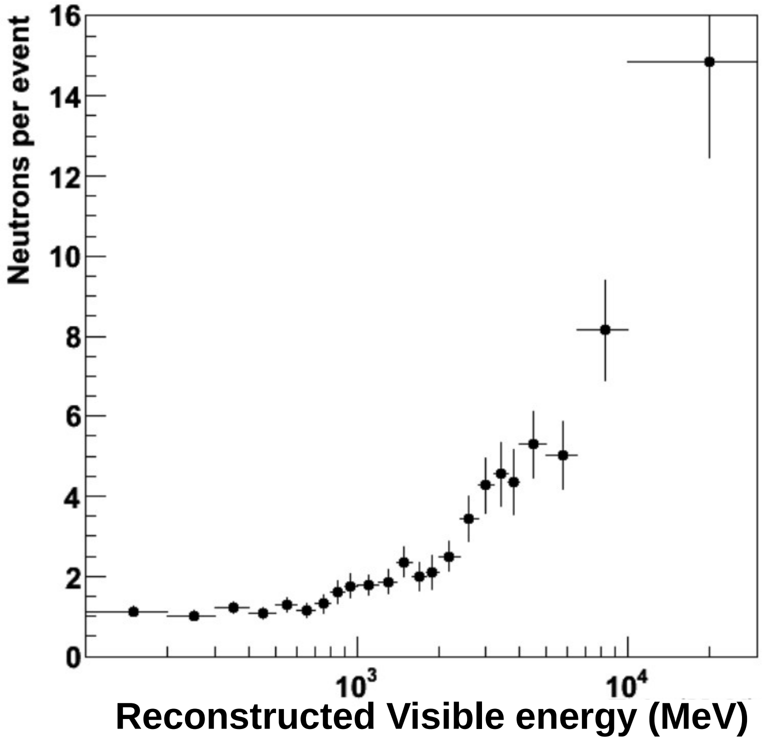

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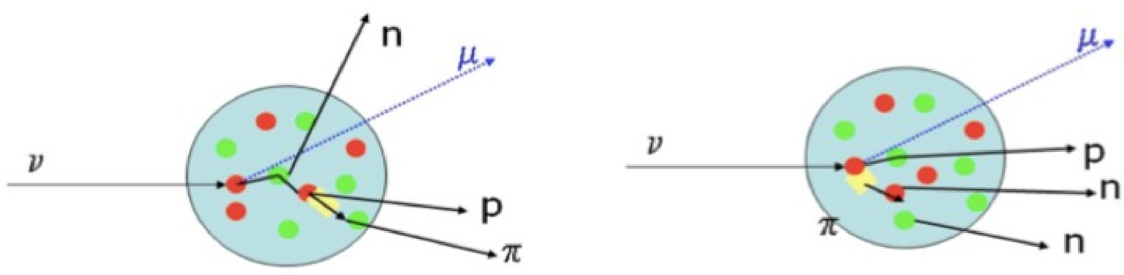

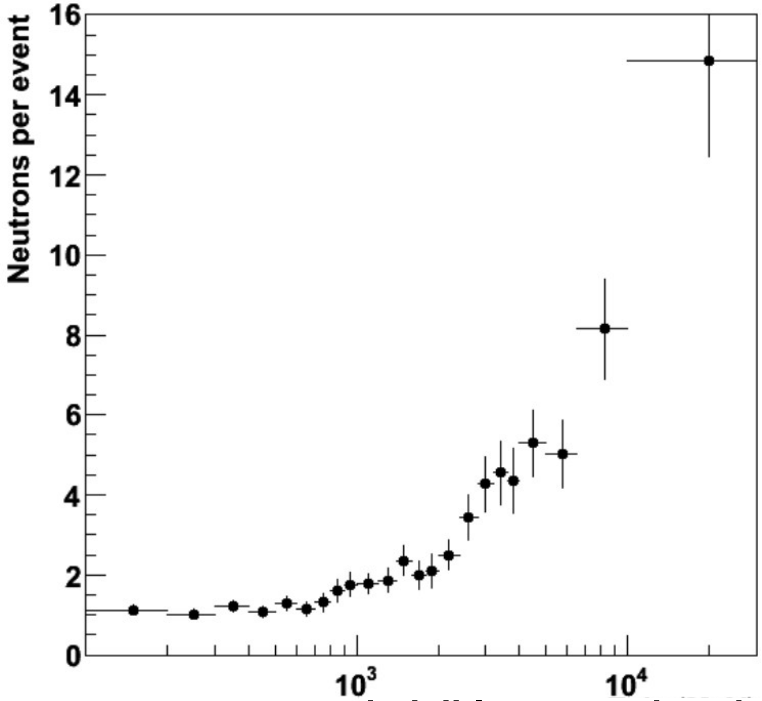

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NOTE: The following figures and results show simulations for SuperKGd and T2KGd

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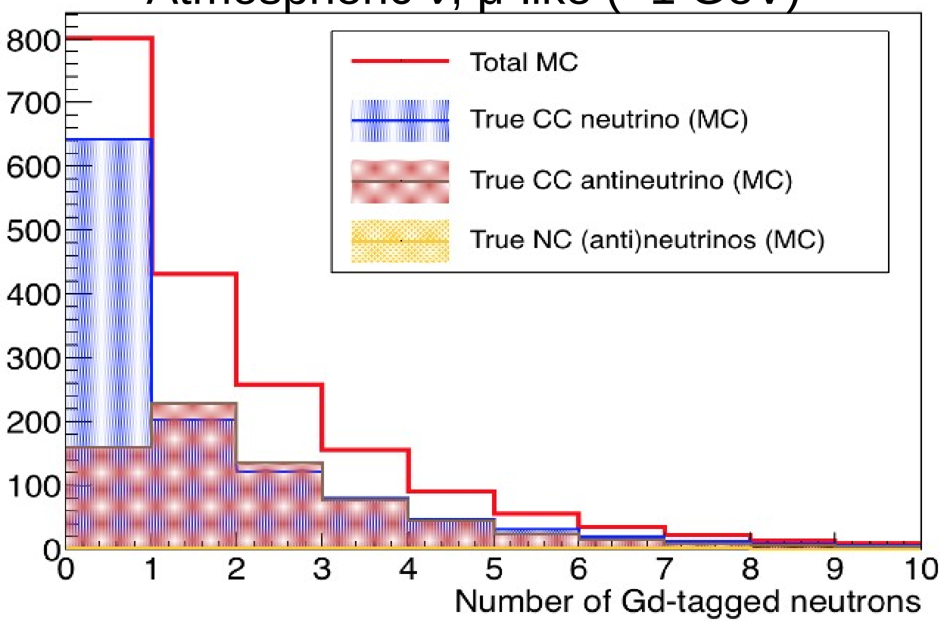
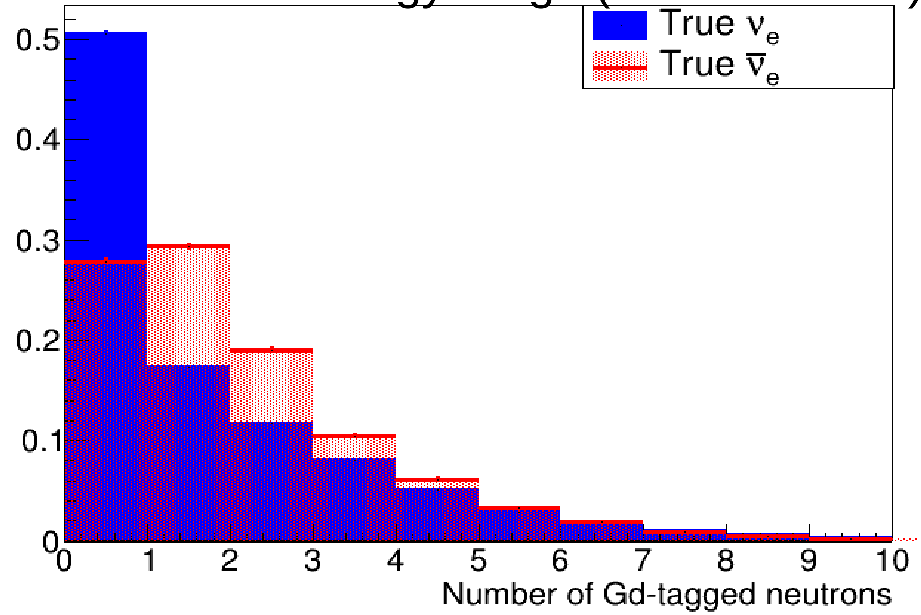
  Despite all this, the neutron multiplicity is still larger for antineutrinos

Atmospheric ν, μ-like (>1 GeV)



DUNE beam energy range (1.5 ~ 2.5 GeV)



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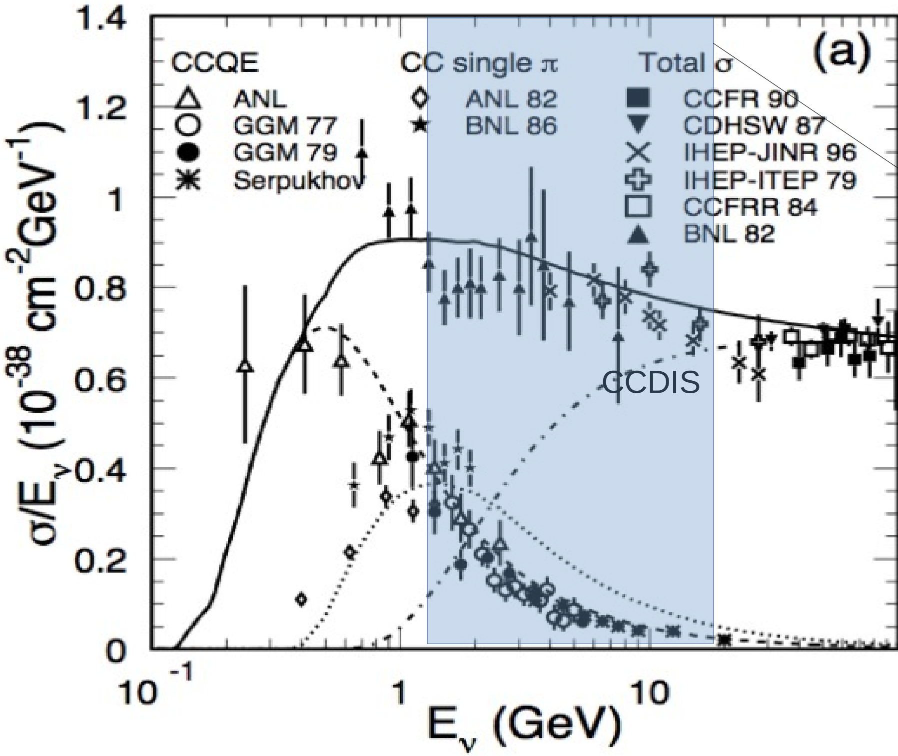
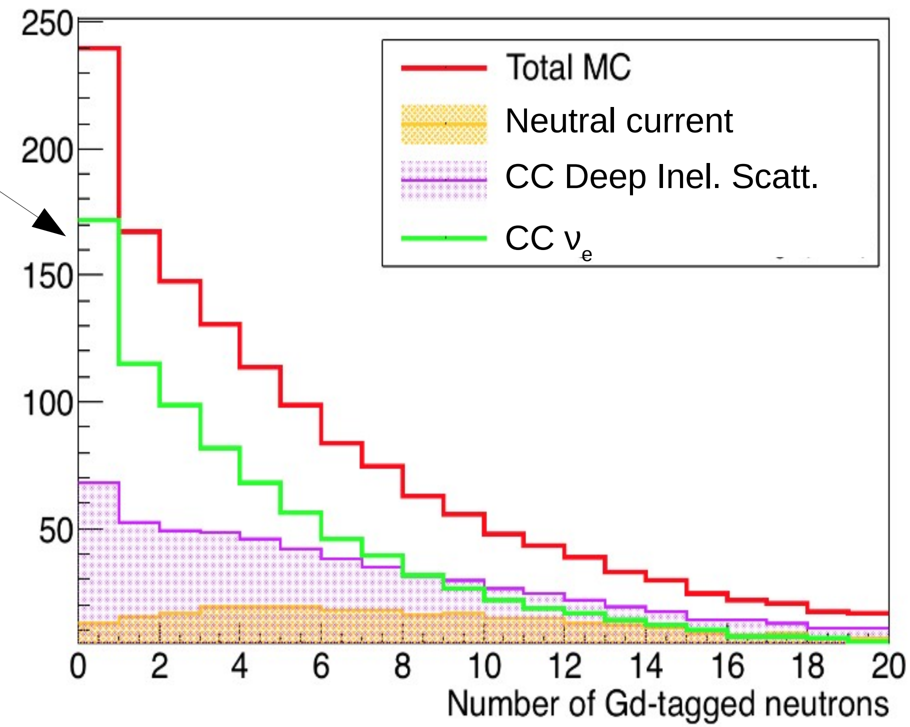
  In this sense, neutron tagging does have some discrimination power to separate between CC, CC-DIS and NC neutrino interactions





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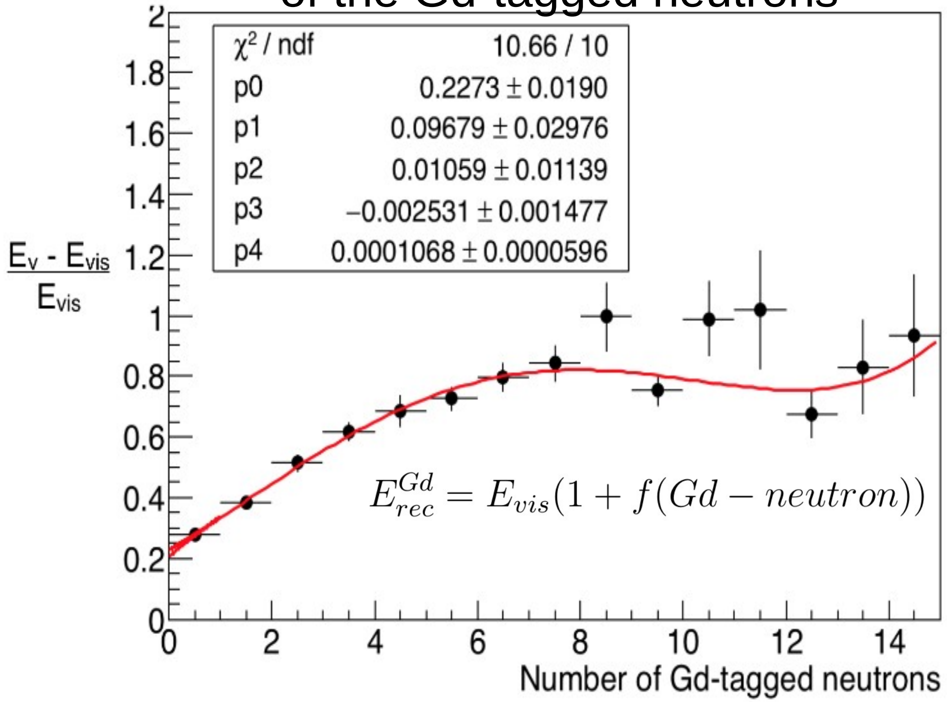
Invisible energy fraction as function of the Gd-tagged neutrons



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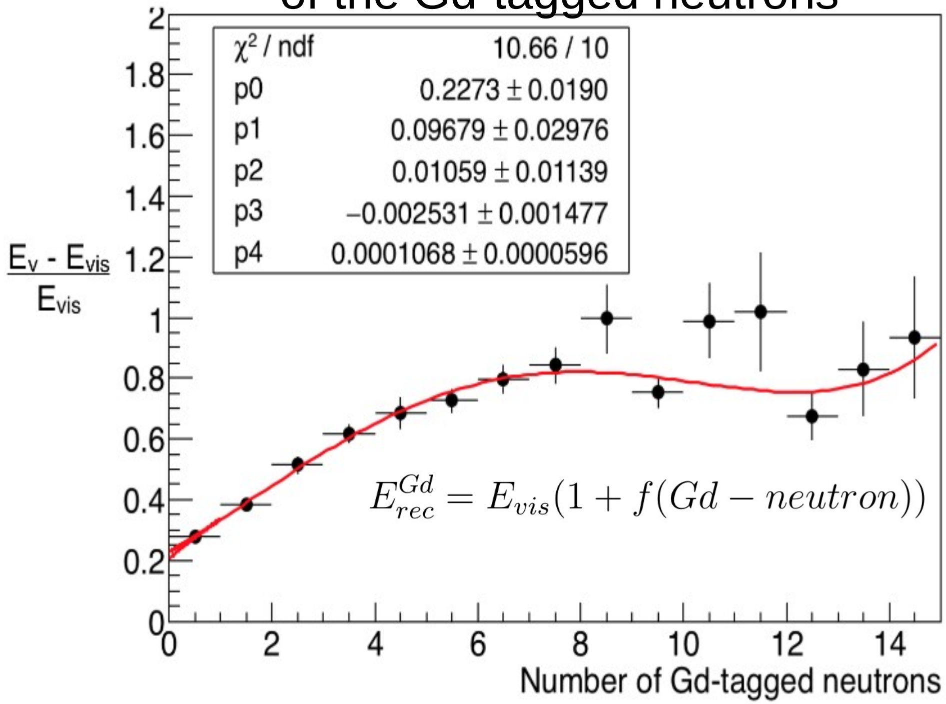
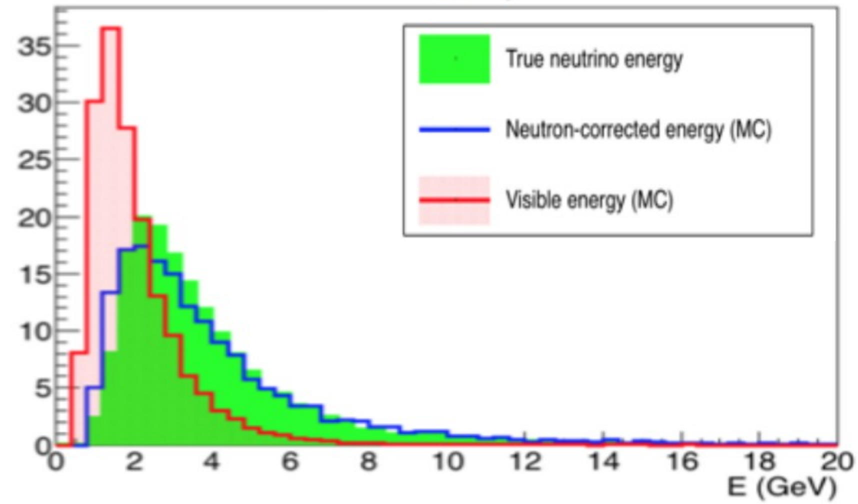
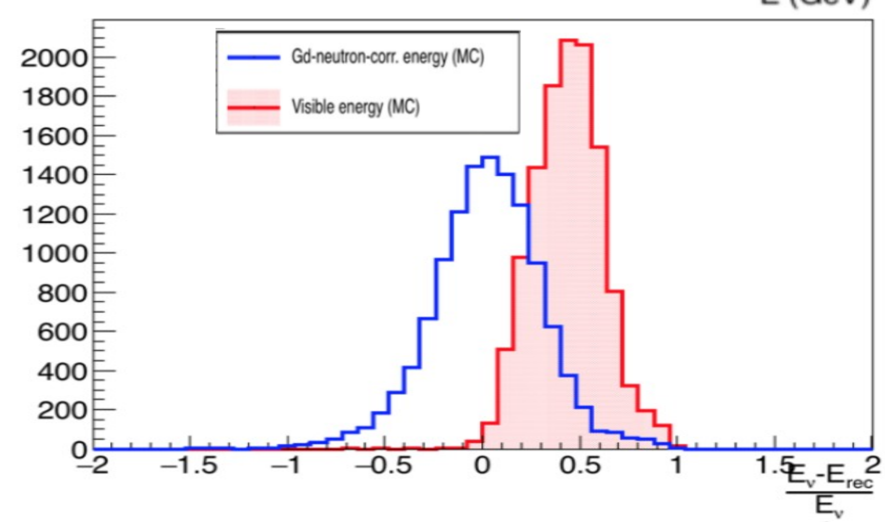




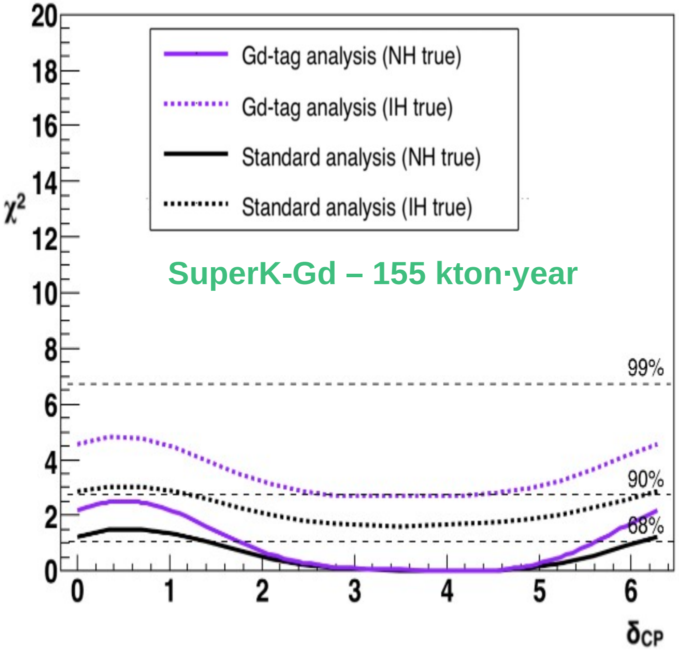


Higher energy physics potential

Atmospheric neutrino oscillations:

All three previous Gd-neutron tagging tools applied improve the atmospheric ν oscillation analysis as compared with the standard case

- Neutrino-antineutrino: performs best at lower energies and improves the sensitivity to $\boldsymbol{\delta_{CP}}$ **and MO**



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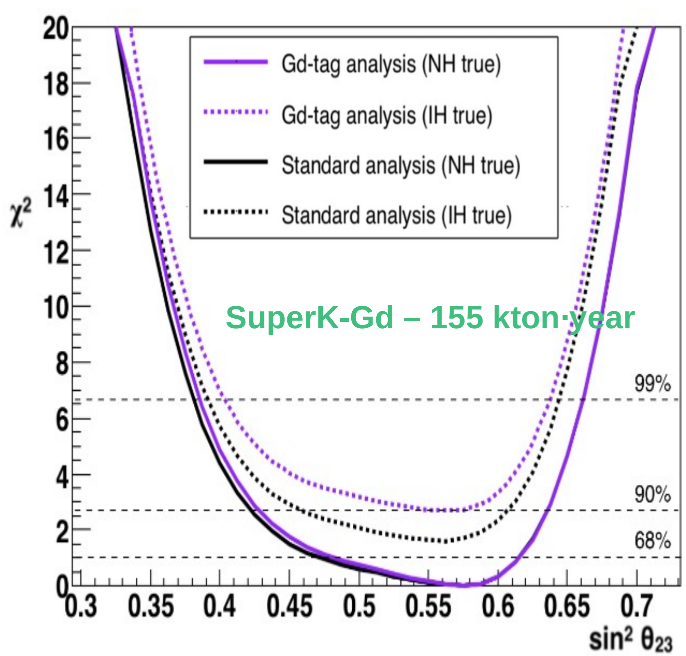

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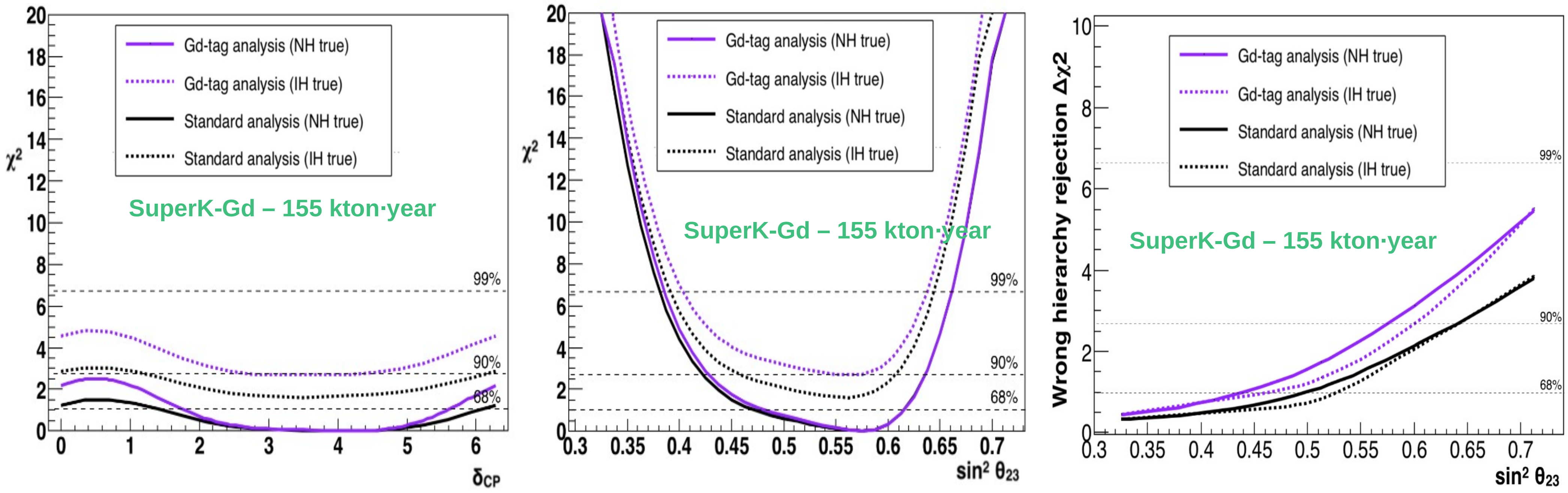
- <u>Energy neutron correction</u>: it affects significantly most of the samples, providing an **overall improvement** in the sensitivity to the oscillation parameters



Higher energy physics potential

Neutrino beam oscillations:
The T2K neutrino beam is very low energy (0.6 GeV) compared to DUNE's future beam

In fact, being the neutrino energy for DUNE ~2 GeV all the three Gd-tagging tools can be applied:

- Detect possible (anti)neutrino backgrounds when the beam is in antineutrino (neutrino) mode
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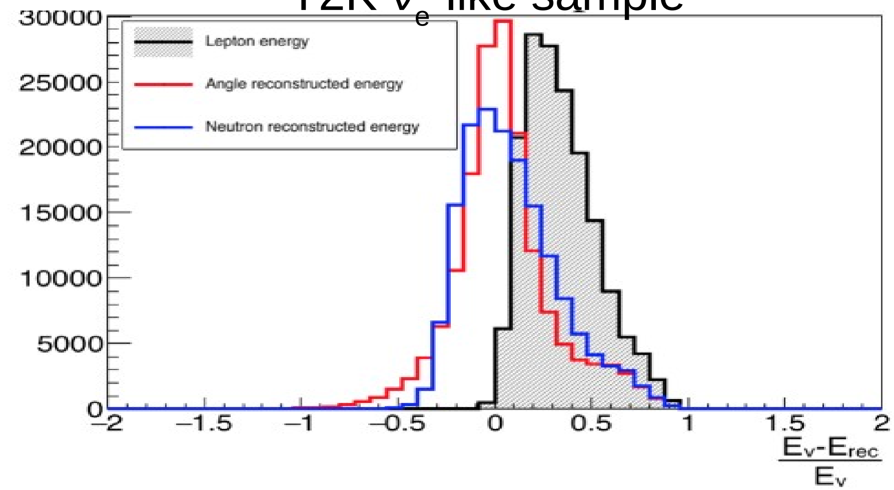
T2K ν_e-like sample



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The largest improvement in sensitivity would come from the ability of detecting beam (anti)neutrino backgrounds

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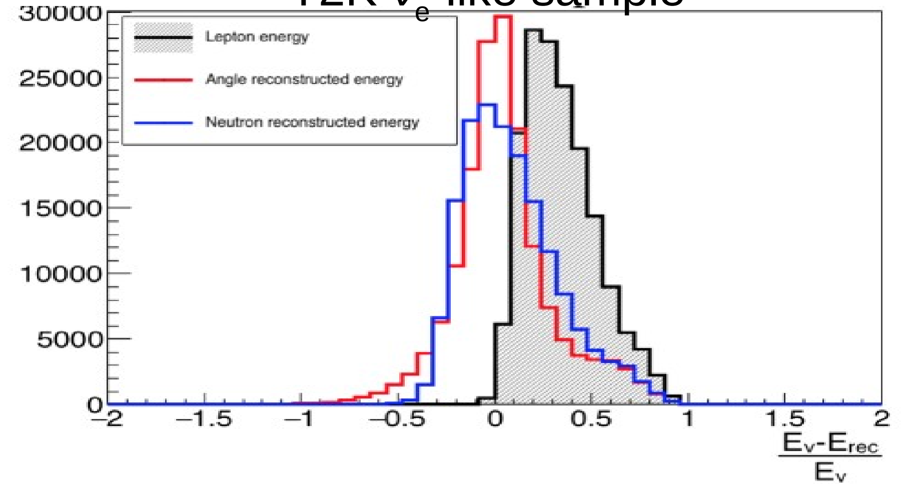
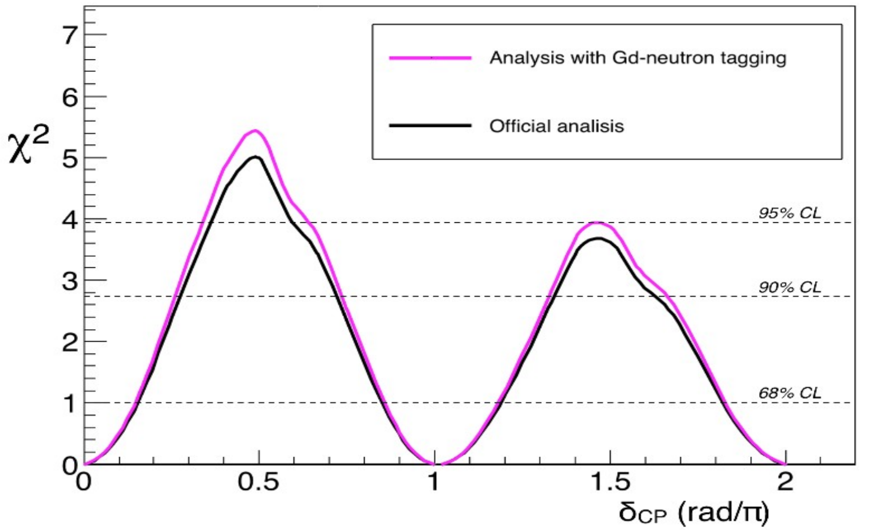


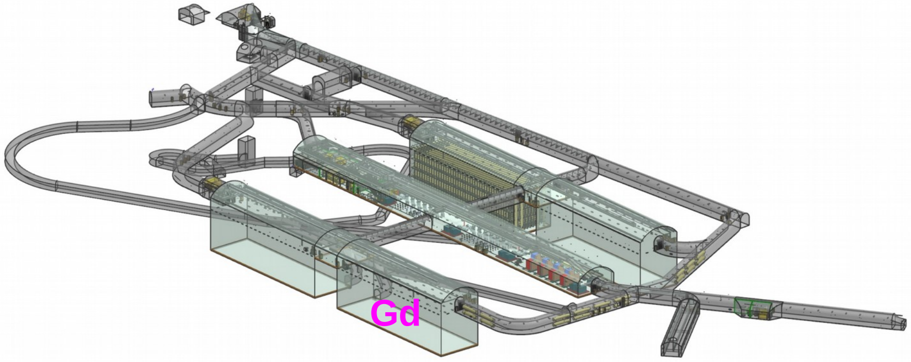
T2K assuming known NH and $3.9 \cdot 10^{21}$ POT



GdUNE!?

Gd-doped water-Cherenkov detectors offer many advantages for physics measurements as compared with regular WC technology

It provides a very complete and well known low-energy neutrino physics program and



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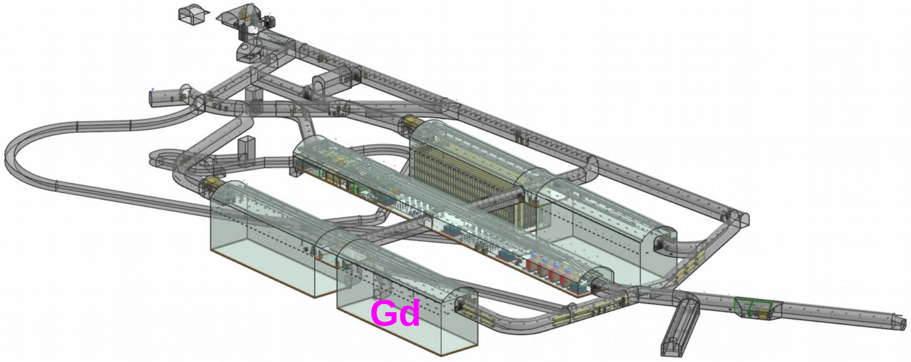

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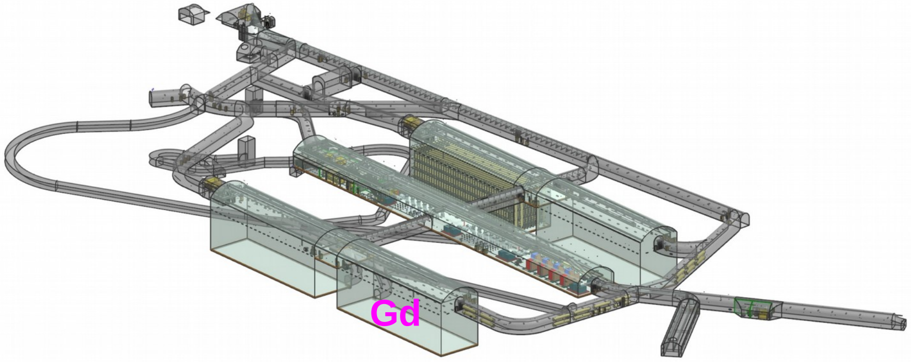

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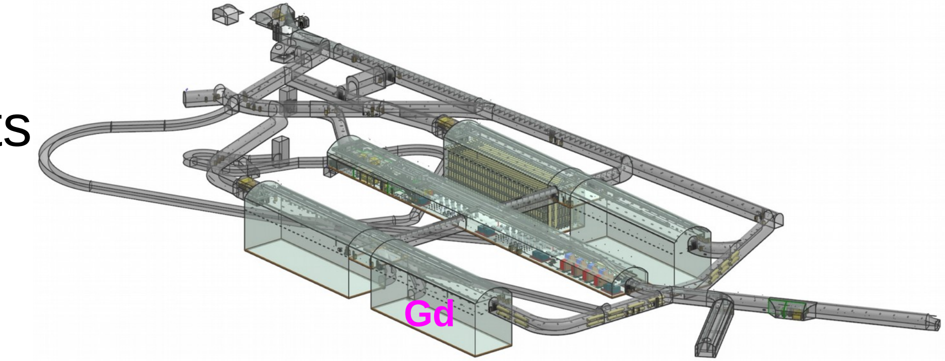

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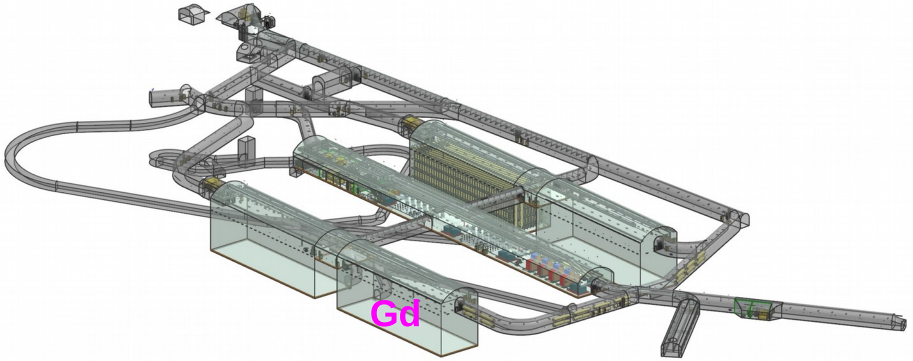
- Improving Gd-water purification systems
- Development of photo-sensors, like LAPPDs in ANNIE (which would be ideal for DUNE’s module given its geometry)
- Depending on the photo-sensor technology the Gd concentration can be adjusted
- Given the size of the cavern, it would be a ~10 kton FV detector (depends on the possible geometry modifications, outer detector…) aiming for a large photocoverage
- Water source in South Dakota?

GdUNE!?

- From the physics point of view, huge knowledge from the data of the existing detectors: neutrino-induced neutron production, constrain uncertainties in neu production processes and their models, ir tuning simulations, etc.



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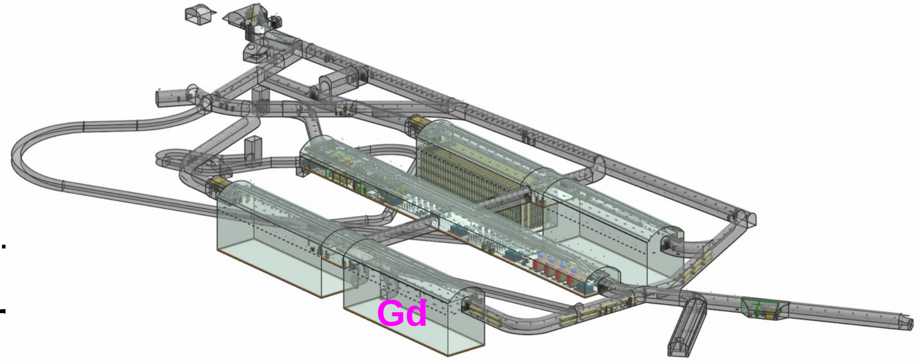

Gd-WC detector could be a serious candidate for the fourth module, cheaper than LAr TPCs, it complements the physics done by other modules and opens the possibility to other physics measurements

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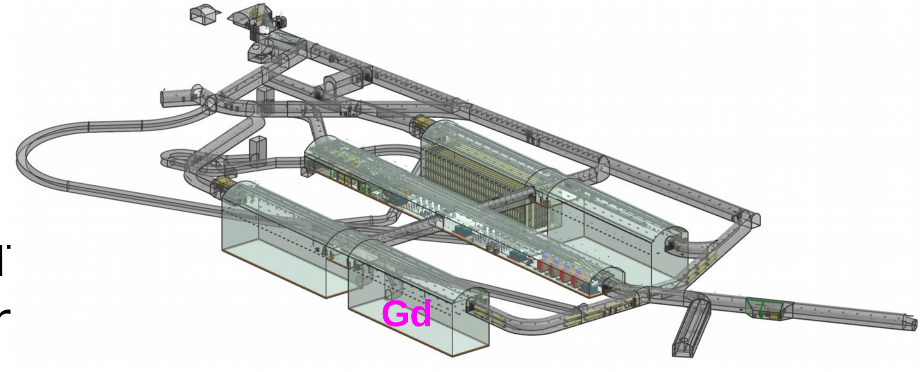

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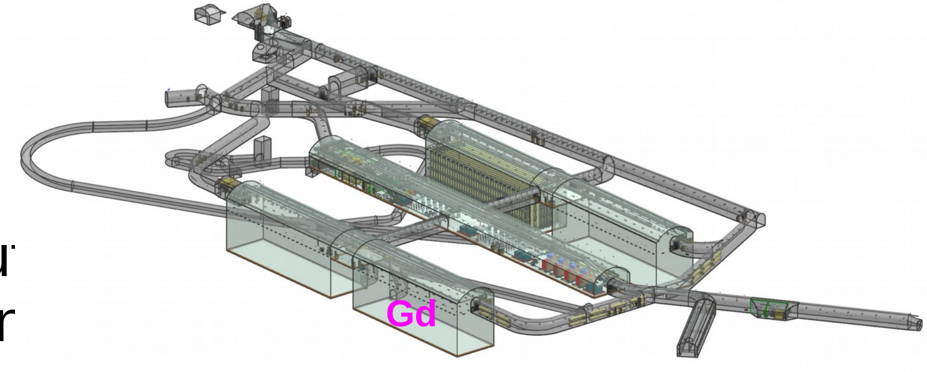

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shall we?